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RESEARCH MEMORANDUM

LANGLEY FULL-SCALE-TUNNEL INVESTIGATION OF THE CHARACTERISTICS IN YAW OF A TRAPEZOIDAL WING OF ASPECT RATIO 4 WITH CIRCULAR-ARC AIRFOIL SECTIONS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation has been conducted at a Reynolds number of approximately 4,100,000 and Mach number of 0.07 to determine the characteristics in yaw of a trapezoidal wing of aspect ratio 4 with circular-arc airfoil sections and 0.20-chord rear and drooped-nose flaps. Measurements of the lift, the lateral force, the rolling moment, and the yawing moment of four configurations were made through a range of angle of attack at several yaw angles ranging from approximately -6° to 18°.

The effective-dihedral parameter of the basic wing is practically zero below a lift coefficient of 0.4 but increases rapidly to 0.0016 at maximum lift. The directional-stability parameter of the basic wing is approximately -0.00015 and the lateral-force parameter is small. Deflecting the full-span rear flaps 60° essentially does not alter the effective-dihedral characteristics of the basic wing, but does increase the directional stability, especially at high lift coefficients. Deflecting the drooped-nose flap 20° produces negative dihedral effect below a lift coefficient of about 0.60 maximum lift coefficient but, as a result of an increased positive variation with lift coefficient, gives a value of 0.0013 for the effective-dihedral parameter at 0.95 of the maximum lift coefficient. This almost linear variation, which agrees well with the calculated relation and with the variations for similar rectangular wings of the same aspect ratio with square tips and conventional round-nose airfoils, probably is the result of a more conventional pressure distribution that occurs on this biconvex airfoil when the nose is drooped. For this drooped-nose condition the directional stability increases with increasing lift coefficient. Deflecting the partial-span rear flap in combination with the drooped-nose flap does not materially change the directional stability or lateral-force characteristics of the drooped-nose condition but reduces the positive variation of dihedral effect with lift coefficient. The lift-curve slope of the basic wing (measured at a lift coefficient of 0.2) decreases from 0.057 to 0.046 as the wing is yawed from 0° to 18.25°.

INTRODUCTION

The aerodynamic characteristics at high Reynolds numbers and low Mach numbers of a trapezoidal wing of aspect ratio 4 with 10-percent-thick circular-arc airfoil sections have been investigated in the Langley full-scale tunnel. The trapezoidal plan form, obtained by cutting the rear part of the tips away from a rectangular plan form at an angle of 30° (fig. 1), appears useful in the completely supersonic regime for a design Mach number of 2, since theoretical calculations indicate that, for this condition, such a wing will have a drag coefficient no greater than that for the airfoil section in two-dimensional flow (references 1 and 2). Results of the investigation of the maximum lift and stalling characteristics of the trapezoidal wing at zero yaw are given in reference 3 and the characteristics in yaw are presented herein.

Measurements of the lift, the lateral force, the rolling moment, and the yawing moment of four configurations were made through a range of angle of attack at several yaw angles ranging from approximately -6° to 18°. The configurations tested in yaw, which were selected from the maximum-lift results of reference 1, were the basic wing and the wing with the full-span 0.20-chord rear plain flap deflected 60°, the full-span 0.20-chord drooped-nose flap deflected 20°, and the partial-span rear and full-span drooped-nose flaps deflected 60° and 20°, respectively, in combination.

COEFFICIENTS AND SYMBOLS

The test data are presented as conventional NACA coefficients of forces and moments referred to the standard stability axes. The Y-axis is assumed to lie along the quarter-chord line of the wing and in the plane of the wing geometric chord lines.

C_L lift coefficient (Lift/qS)

C_Y lateral-force coefficient (Y/qS)

C_l rolling-moment coefficient (L/qSb)

C_n yawing-moment coefficient (N/qSb)

$C_{L_{max}}$ maximum lift coefficient

α angle of attack, degrees

ψ angle of yaw, degrees

R Reynolds number $(\rho Vc/\mu)$

δ flap deflection, degrees

S wing area (232.0 sq ft)

c wing chord (9.23 ft)

b wing span (30.47 ft)

A aspect ratio $\left(b^2/S\right)$

Y lateral force

L rolling moment

N yawing moment

q dynamic pressure

ρ mass density of air

μ coefficient of viscosity

λ taper ratio

Subscripts:

n drooped-nose flap

f rear flap

ψ denotes partial derivative of coefficient with respect to yaw in degrees $\left(\text{example: } C_{l_\psi} = \frac{\partial C_l}{\partial \psi}\right)$

MODEL

The model of this investigation is the same as that used in the tests of reference 3. The geometric characteristics of the wing, and the arrangement of the high-lift devices are shown in figures 1 and 2. Photographs of the wing mounted on yaw supports in the Langley full-scale tunnel are presented as figure 3. The wing has a 10-percent-thick biconvex airoil section, the ordinates of which may be found in reference 4. The wing has no geometric twist or dihedral.

The 0.20c drooped-nose flap tested was 100-percent span, and the partial-span and full-span 0.20c rear flaps were 45 and 95 percent of the trailing-edge span, respectively. The rear flaps had a 12-inch cut-out at the wing center line to provide clearance for the rear support sting (figs. 1 and 3(b)). Both the drooped-nose and rear flaps were deflected about hinges on the lower wing surface. In the flap-deflected tests the gap on the upper wing surface was sealed with a faired cover plate.

METHODS AND TESTS

The trapezoidal wing was mounted on two main support struts and a rear strut which, by varying the length, provided a means of changing angle of attack. The full-scale tunnel and balance system used for the tests are described in reference 5.

The configurations tested in yaw were the basic wing and three flapped configurations with the respective flap deflections which gave the highest maximum lift for the tests of reference 1. Those flapped configurations were the full-span rear flap deflected 60°, the full-span drooped-nose flap deflected 20°, and the full-span drooped-nose flap deflected 20° in combination with the partial-span rear flap deflected 60°.

Measurements of the lift, the lateral force, the rolling moment, and the yawing moment were made through an angle-of-attack range of from about 0° through the stall at 2° increments, except near the stall, where 1° increments were used. The basic wing and the full-span rear flap configurations were tested at approximately 6° yaw increments from yaw angles of -6° to 18°, whereas the remaining configurations were tested only at approximate yaw angles of 0° and $\pm 6^\circ$ to obtain stability parameters. Inasmuch as reference 1 indicated essentially no scale effect for the sharp leading-edge wing, all tests were run at a Reynolds number of approximately 4,100,000 corresponding to a Mach number of about 0.07.

All data have been corrected for the wind-tunnel jet-boundary and blocking effects, the stream alinement, and for the tare drag of the support system.

RESULTS AND DISCUSSION

The test data of the basic wing and of the wing with the full-span rear flap are presented in figure 4. The variations with lift coefficient of the effective dihedral, directional stability, and side-force parameters (determined at $\psi = 0^\circ$ from the basic data) are shown in figure 5 for all the configurations investigated. Figure 6 gives the lift curves for various angles of yaw.

Lateral Characteristics of Basic Wing

The effective dihedral of the basic wing (fig. 5(a)) is practically zero at small and moderate lift coefficients but increases rapidly to 0.0016 at $C_{L_{max}}$. This rapid increase of effective dihedral near $C_{L_{max}}$

is typical of a rectangular wing with either conventional or sharp leading-edge airfoil sections. The difference between the effective-dihedral variation at lower lift coefficients of the basic trapezoidal wing and the steady positive variation with lift coefficient shown in references 6 and 7 for rectangular wings of similar aspect ratio with square tips and conventional round leading-edge airfoils can probably be ascribed both to the sharp leading edge of the circular-arc airfoil and to the cutaway wedge-shape tips. Unpublished data for a similar rectangular wing of aspect ratio 3.4 show a parabolic increase of C_{l_ψ} with C_L and higher C_{l_ψ} values throughout the C_L range than for the basic trapezoidal wing. The parabolic variation must be attributed to the sharp leading edge and the increase in C_{l_ψ} probably can be ascribed both to the lower aspect ratio and to the difference in tip shape. Swept wings with circular-arc airfoil sections also have been found to have decidely different effective-dihedral characteristics than geometrically identical wings with conventional sections. The directional-stability parameter C_{n_ψ} is approximately -0.00015 except at the stall where it has a sharp negative break; and the C_{Y_ψ} values are low. The basic data of figure 4(a) show almost linear variations of C_l, C_n, and C_Y throughout the yaw range investigated.

The lift-curve slope of the basic wing (measured at $C_L = 0.2$) decreases from 0.057 at 0° yaw to 0.046 at 18.25° yaw (fig. 6). The maximum lift coefficient decreases from 0.63 to 0.60 in the yaw range investigated and also occurs at a higher angle of attack, 18° instead of 16°, for the highest yaw angle tested.

Effect of Flap Deflection on Lateral Characteristics

Rear flaps.- By deflecting the full-span rear flap 60° the dihedral characteristics of the basic wing are essentially duplicated wherein C_{l_ψ} values are low below $0.85C_{L_{max}}$, but rapidly increase up to 0.0011 at $C_{L_{max}}$ (fig. 5(b)). The C_{Y_ψ} variation is practically the same as for the basic wing, but the directional stability is greater than that for the basic wing with C_{n_ψ} varying from -0.00035 to -0.00100 at the stall. The basic data of figure 4(b) show that the C_{Y_ψ} values measured at $\psi = 0°$ generally hold throughout the yaw range investigated; however, the slopes of the rolling-moment and yawing-moment curves decrease at the larger yaw angles.

Drooped-nose flap.- The effect of deflecting the full-span drooped-nose flap 20° is to give a large, steady, positive variation of C_{l_ψ} with C_L (fig. 5(c)) which is similar to that for rectangular wings of similar aspect ratio with square tips and conventional round-nose airfoil sections. Negative-dihedral effect is indicated below a C_L of 0.54 but $\partial C_{l_\psi}/\partial C_L$ increases positively at high lift coefficients so that at $0.95C_{L_{max}}$ a C_{l_ψ} value of 0.0013 is obtained. The negative C_{l_ψ} values at low lift-coefficients are not very significant because the drooped-nose configuration probably would not be flown at high speeds. The generally linear effective-dihedral variation with lift coefficient can probably be attributed to the fact that drooping the nose delays the early separation at the sharp leading edge and thereby produces a pressure distribution more like that for conventional airfoil sections. Weissinger derives in reference 8 an empirical formula for determining dihedral effect for the low and moderate lift-coefficient range which, corrected to apply to the total wing span, is $57.3\frac{\partial C_{l_\psi}}{\partial C_L} = \frac{K}{A}\left[\frac{\lambda + 0.29(1 - \lambda)}{\lambda + 1}\right] - 0.10$ where K is an empirical constant. Using a K value of 1.56 as determined experimentally in reference 7, the calculated value of $\partial C_{l_\psi}/C_L$ of 0.0017 is in excellent agreement with the measured value. Unpublished data for a similar rectangular wing with square tips and aspect ratio of 3.4 show that the drooped-nose flap and several other leading-edge high-lift devices that delay early leading-edge separation produce linear positive C_{l_ψ} variations with C_L which also agree well with calculated values of $\partial C_{l_\psi}/\partial C_L$ as determined from Weissinger's empirical formula.

Rear and drooped-nose flaps in combination.- Deflecting the partial-span rear flap 60° in combination with the full-span drooped-nose flap 20° reduces both $\partial C_{l_\psi}/\partial C_L$ and C_{l_ψ} considerably below those for the configuration with the drooped-nose flap alone. The C_{l_ψ} variation with C_L is positive throughout the entire C_L range, however, and gives a C_{l_ψ} value of 0.0006 at $0.95C_{L_{max}}$ (fig. 5(d)). The directional-stability and lateral-force characteristics are similar to those for the configuration with drooped-nose flap alone.

SUMMARY OF RESULTS

The significant results of the investigation of a trapezoidal wing in yaw at an approximate Reynolds number of 4,100,000 and Mach number of 0.07 may be summarized as follows:

1. The effective-dihedral parameter of the basic wing is practically zero below a lift coefficient of 0.4, but increases rapidly to 0.0016 at maximum lift. The directional-stability parameter of the basic wing is approximately -0.00015 and the lateral-force parameter is small.

2. Deflecting the full-span rear flaps essentially does not alter the effective-dihedral characteristics of the basic wing, but does increase the directional stability, especially at high lift coefficients.

3. Deflecting the drooped-nose flap 20° produces negative dihedral effect below a lift coefficient of about 0.60 maximum lift coefficient but, as a result of an increased positive variation with lift coefficient, gives a value of 0.0013 for the effective-dihedral parameter at 0.95 of the maximum lift coefficient. This almost linear variation, which agrees well with the calculated relation and with the variations for similar rectangular wings of the same aspect ratio with square tips and conventional round-nose airfoils, probably is the result of a more conventional pressure distribution that occurs on this biconvex airfoil when the nose is drooped. For this drooped-nose condition the directional stability increases with increasing lift coefficients. Deflecting the partial-span rear flap in combination with the drooped-nose flap does not materially change the directional-stability or lateral-force characteristics of the drooped-nose condition, but reduces the positive variation of dihedral effect with lift coefficient.

4. The lift-curve slope of the basic wing (measured at a lift coefficient of 0.2) decreases from 0.057 to 0.046 as the wing is yawed from 0° to 18.25°.

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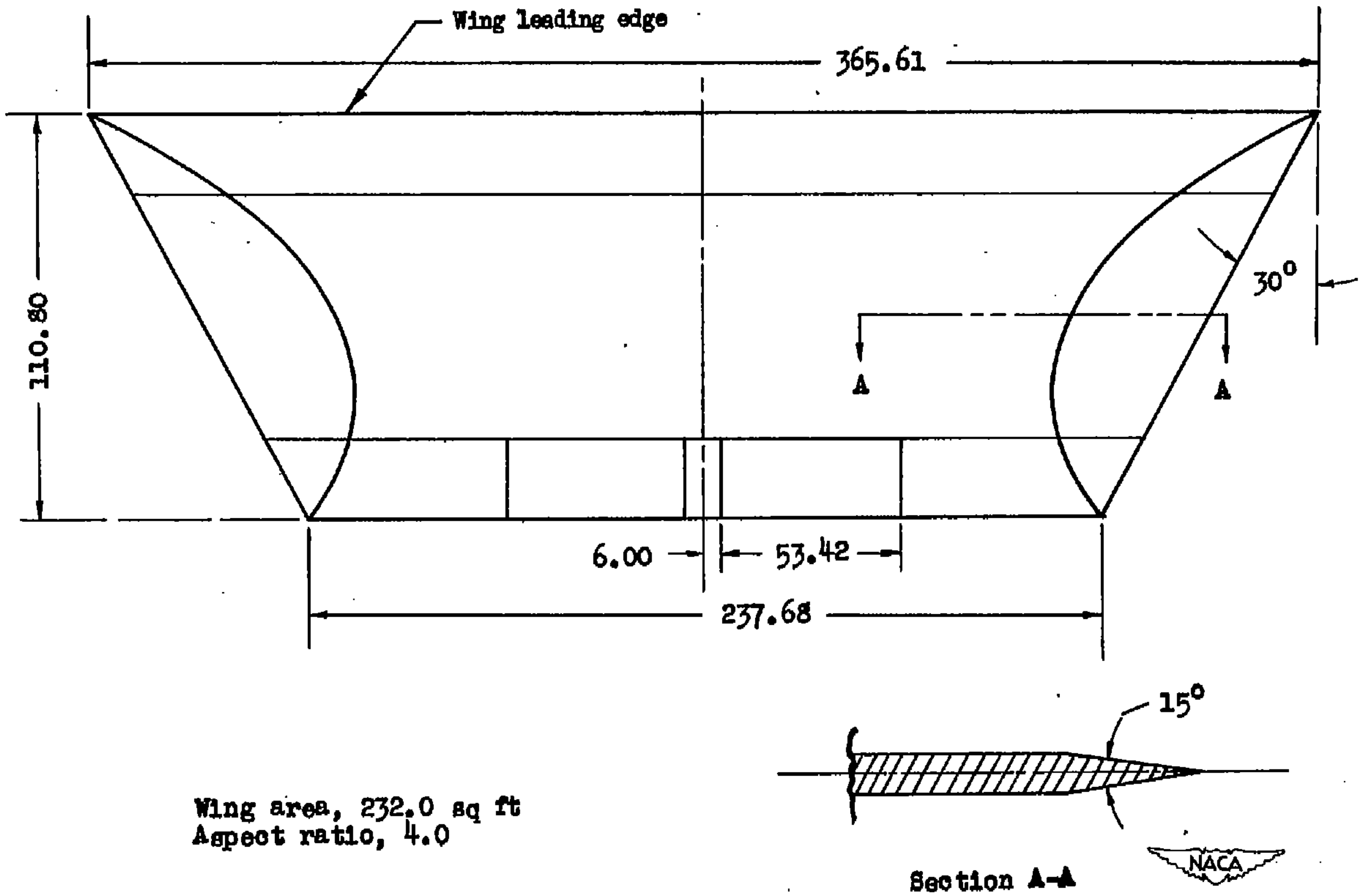


Figure 1.- Geometric characteristics of trapezoidal wing. All dimensions are given in inches.

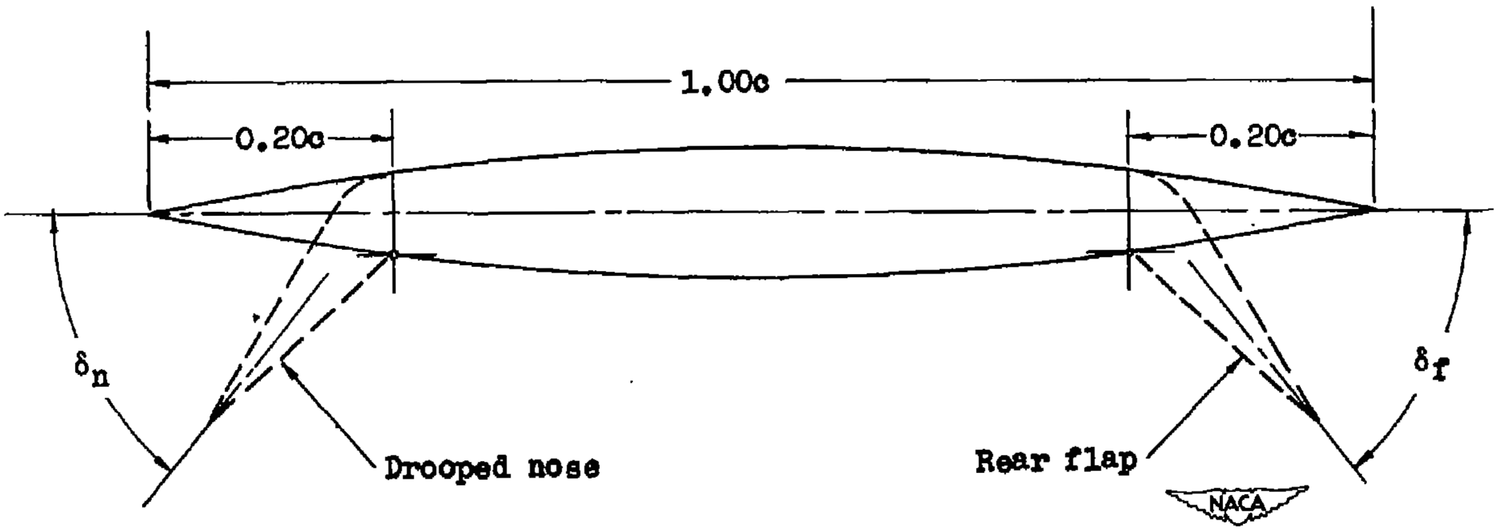
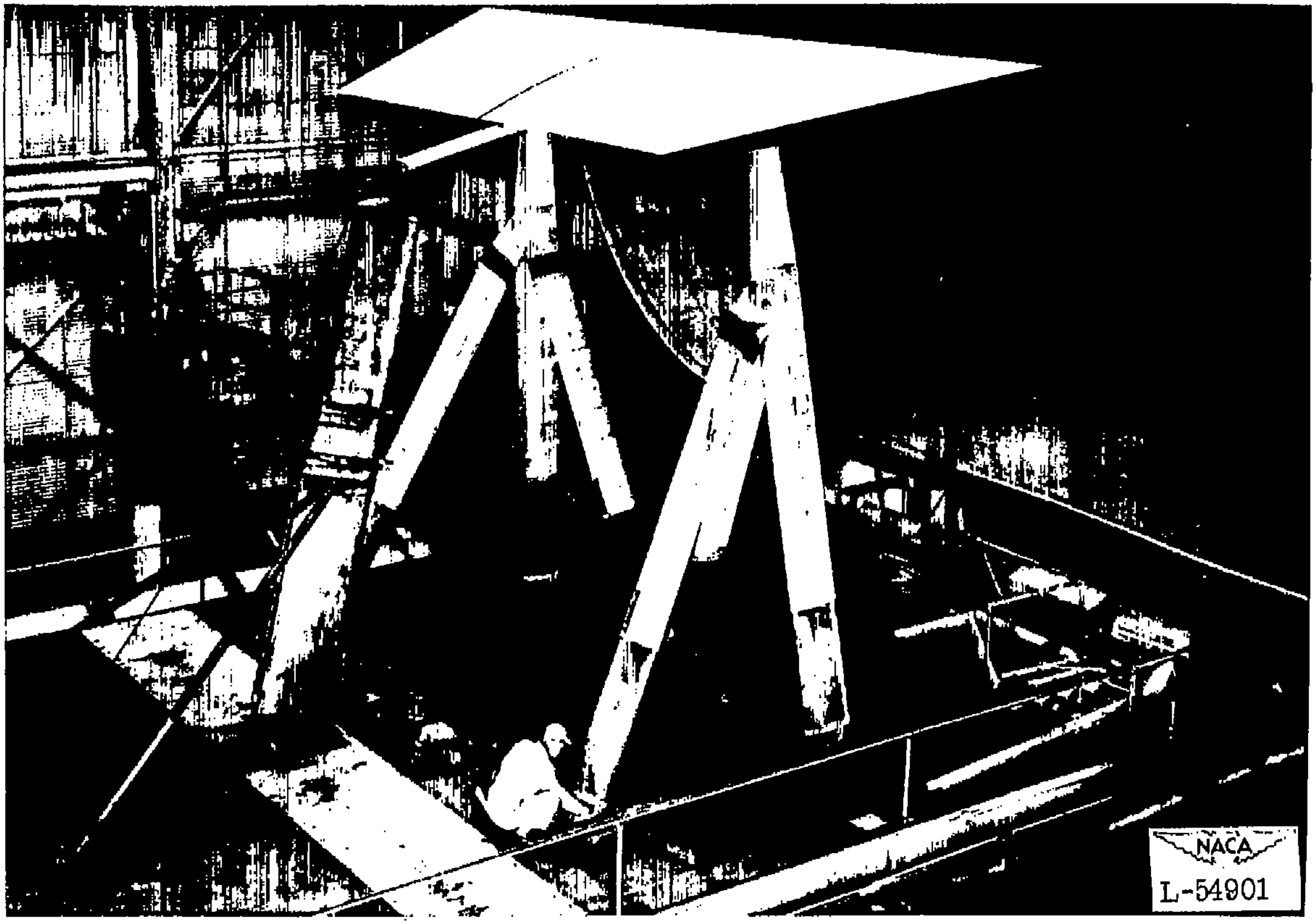
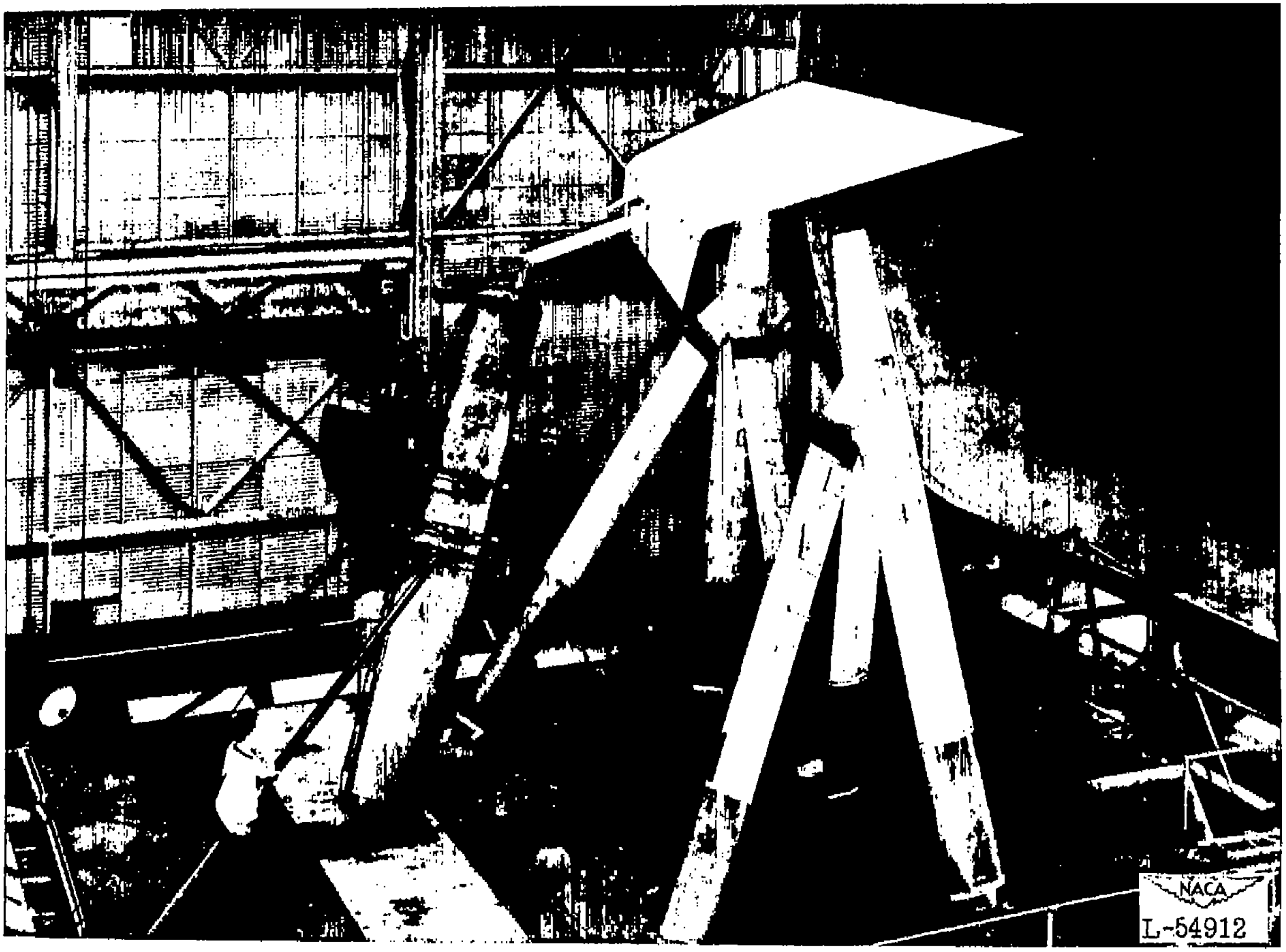


Figure 2.- Ten-percent-thick biconvex airfoil section showing arrangement of drooped-nose and rear flaps.



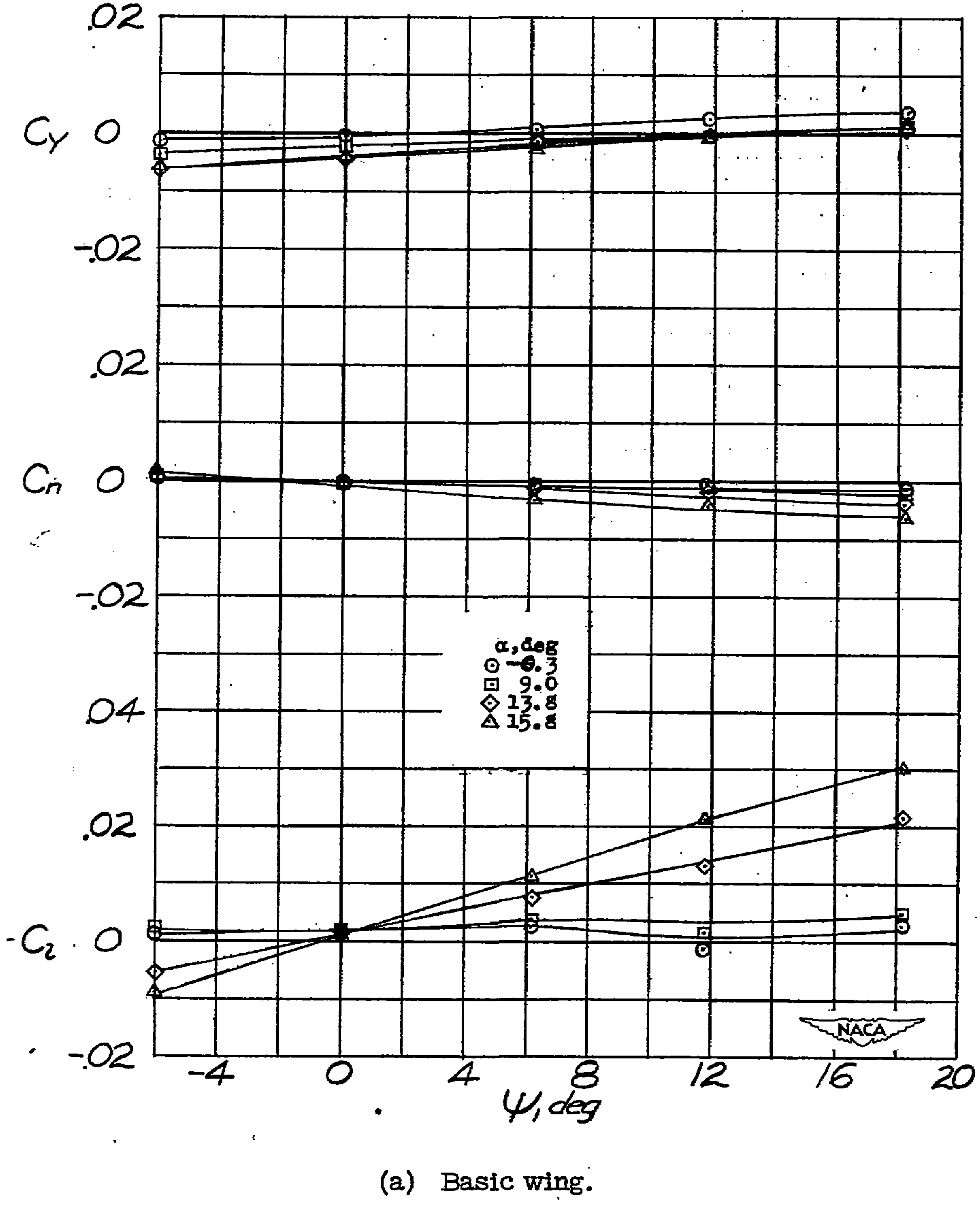
(a) Basic wing, $\psi = 0^{\circ}$.

Figure 3.- Photographs of the trapezoidal wing mounted in the Langley full-scale tunnel.



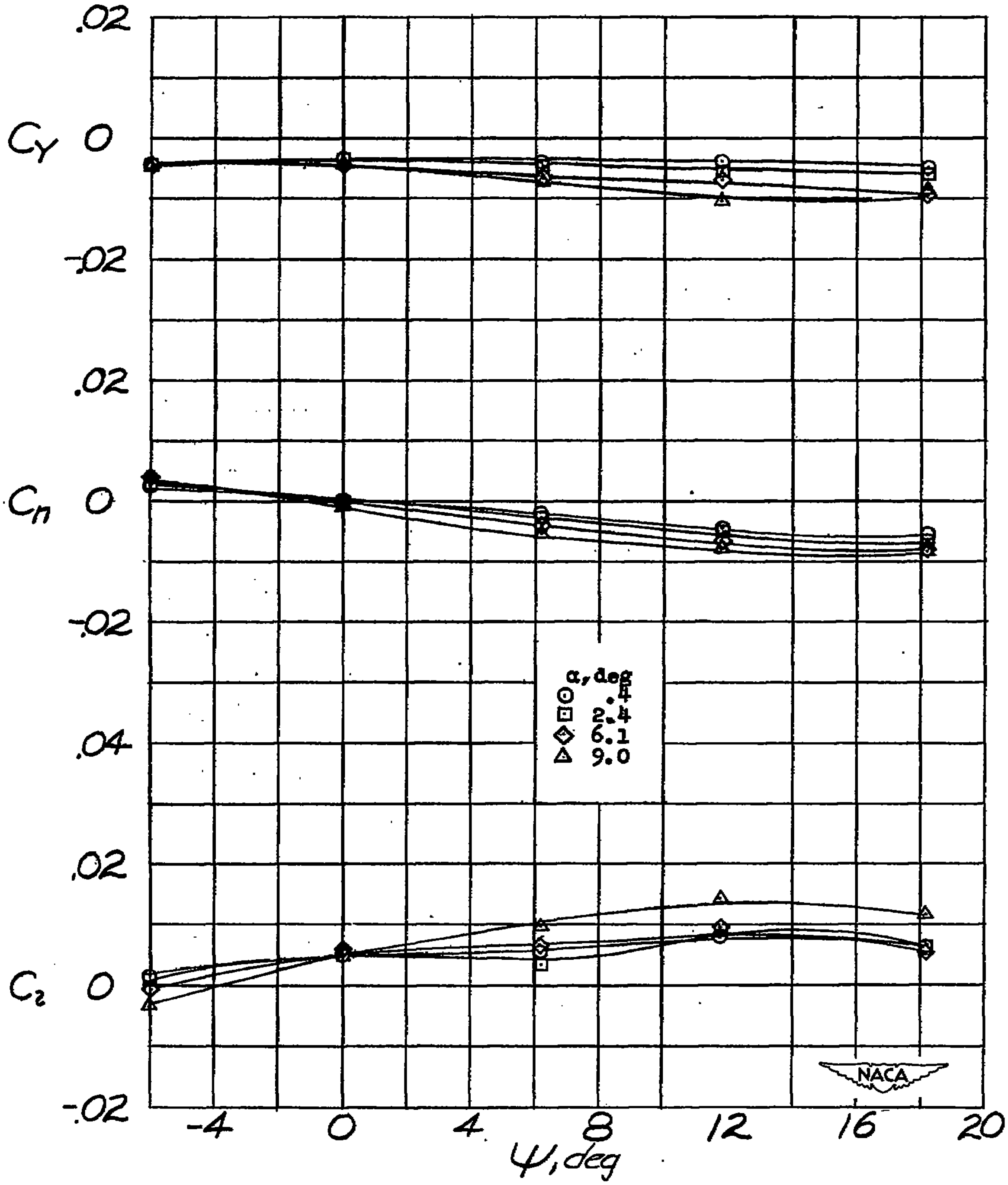
(b) $\delta_f = 60^{\circ}$; $\psi = 18.25^{\circ}$.

Figure 3.- Concluded.



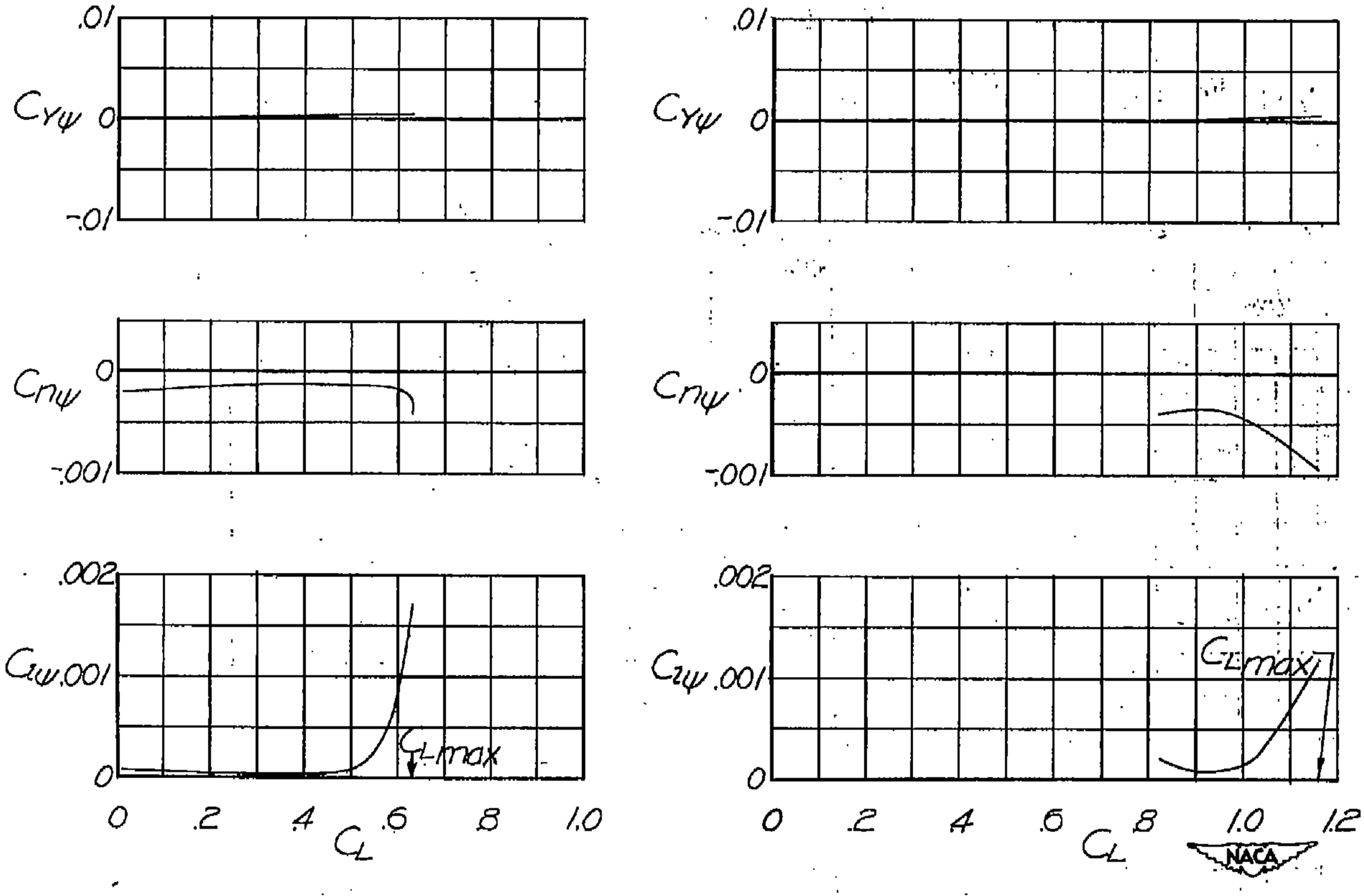
(a) Basic wing.

Figure 4.- Variation of C_l, C_n, and C_Y with ψ.



(b) $\delta_{f_{full\ span}} = 60^{\circ}$; $\delta_n = 0^{\circ}$.

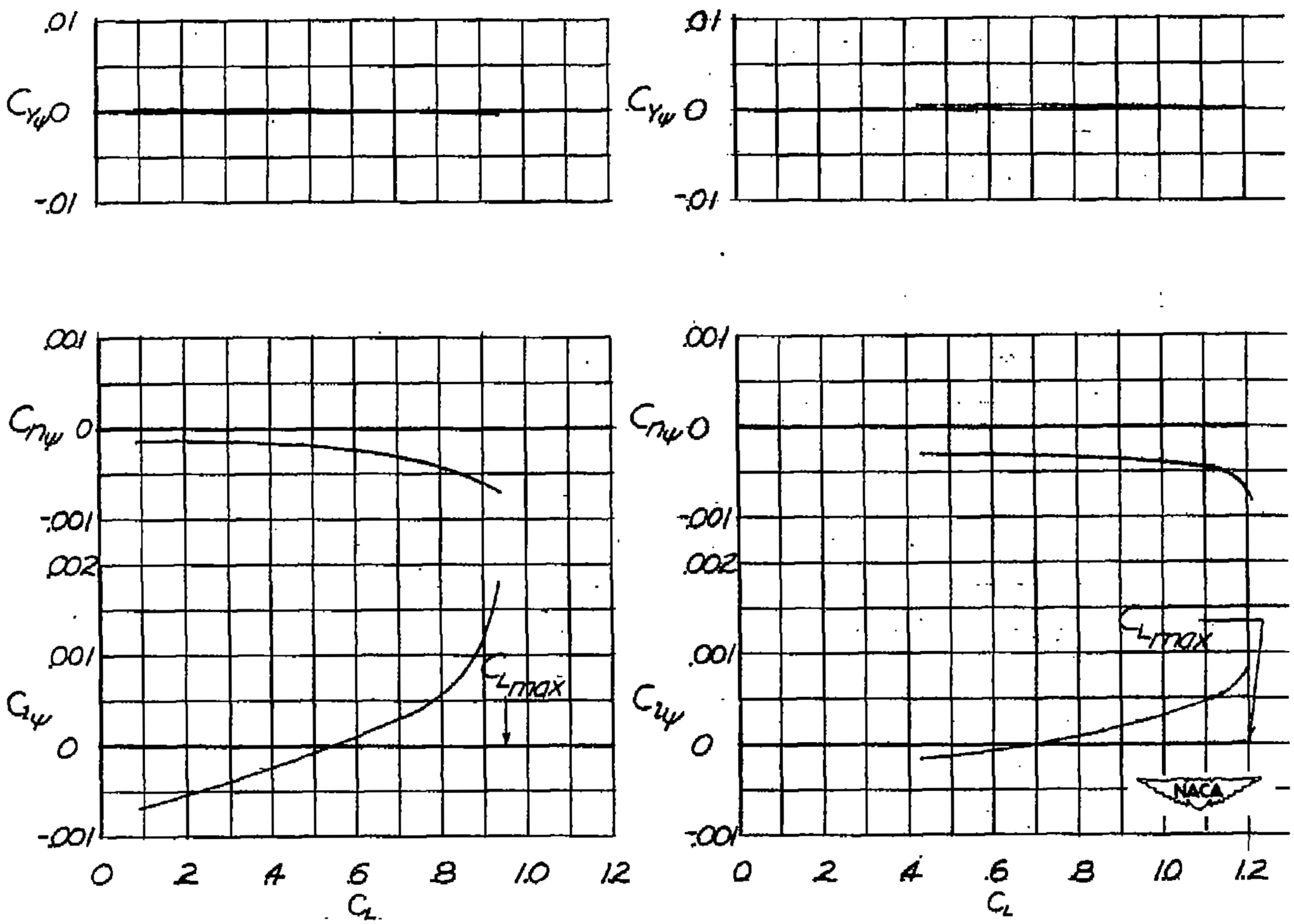
Figure 4.- Concluded.



(a) Basic wing.

(b) $\delta_{f_{\text{full span}}} = 60^{\circ}$; $\delta_n = 0^{\circ}$.

Figure 5.- Variation of lateral characteristics of trapezoidal wing with lift coefficient.



(c) $\delta_f = 0^{\circ}$; $\delta_n = 20^{\circ}$.

(d) $\delta_{f_{\text{partial span}}} = 60^{\circ}$; $\delta_n = 20^{\circ}$.

Figure 5.- Concluded.

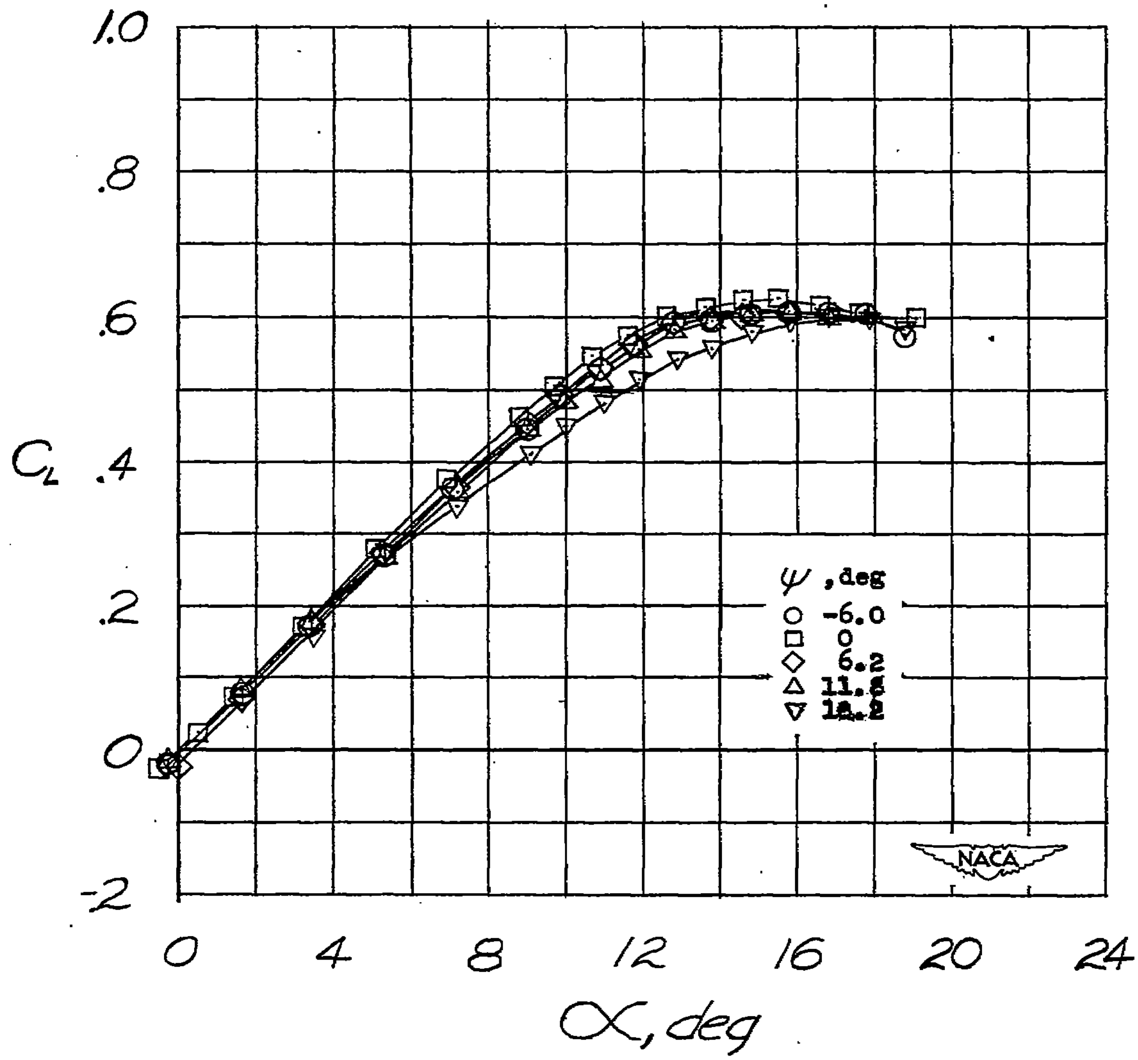


Figure 6.- Effect of yaw on lift of basic trapezoidal wing.